MURI review

Oct. 2012

GATOR Engineering
UNIVERSITY OF FLORIDA

Topics-role of defects on reliability

I. Effect of Buffer Structures on AlGaN/GaN HEMT Reliability

II. The effects of proton irradiation on the reliability of InAlN/GaN high electron mobility transistors

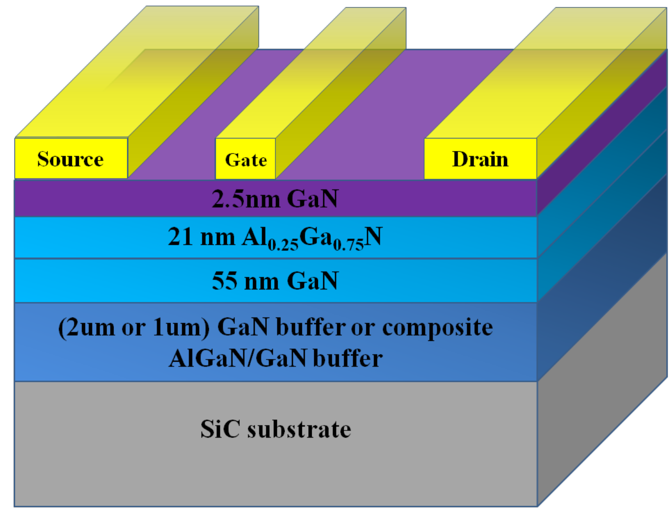
II. Dependence on proton energy of degradation of AlGaN/GaN high electron mobility transistors

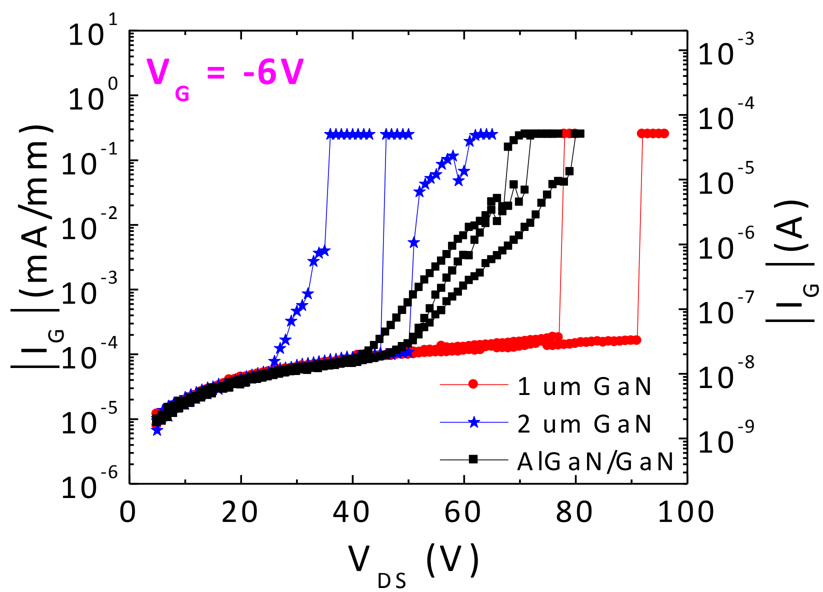
Part I

Effect of buffer structures on AlGaN/GaN HEMT reliability

Results

- **HEMTs with 3 different types of buffer layers, GaN/AlGaN composite layer, or 1 or 2 µm GaN thick layers were compared. Devices with the thick GaN buffer layer showed the lowest critical voltage (V_{cri}) during off-state drain step-stress.**
- **The $V_{off\text{-}state}$ for HEMTs with thin GaN and composite buffers were ~100V, this degraded to 50-60V for devices with thick GaN buffers.**
- **Peak electric field near the gate edge is reduced for HEMTs with thin buffer layers, this leads to a higher critical voltage for the onset of leakage current and better reliability during bias stressing.**





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Part II

The effects of proton irradiation on the reliability of InAlN/GaN high electron mobility transistors

Experiments

Irradiation conditions:

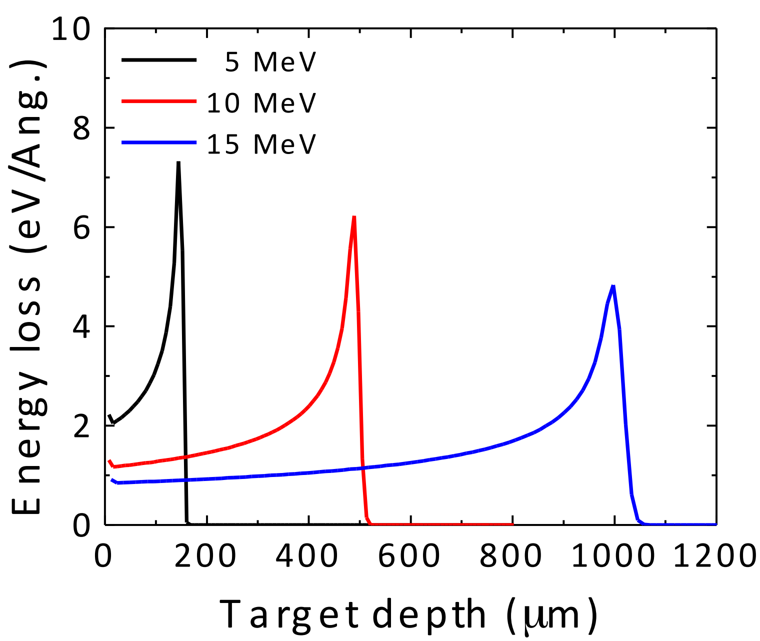
- **Proton energies of 5, 10 and 15 MeV at a fixed fluence of 5×10^{15} cm^{-2};**
- **Proton doses of 2×10^{11}, 2×10^{13} and 2×10^{15} cm^{-2} at a fixed energy of 5MeV.**

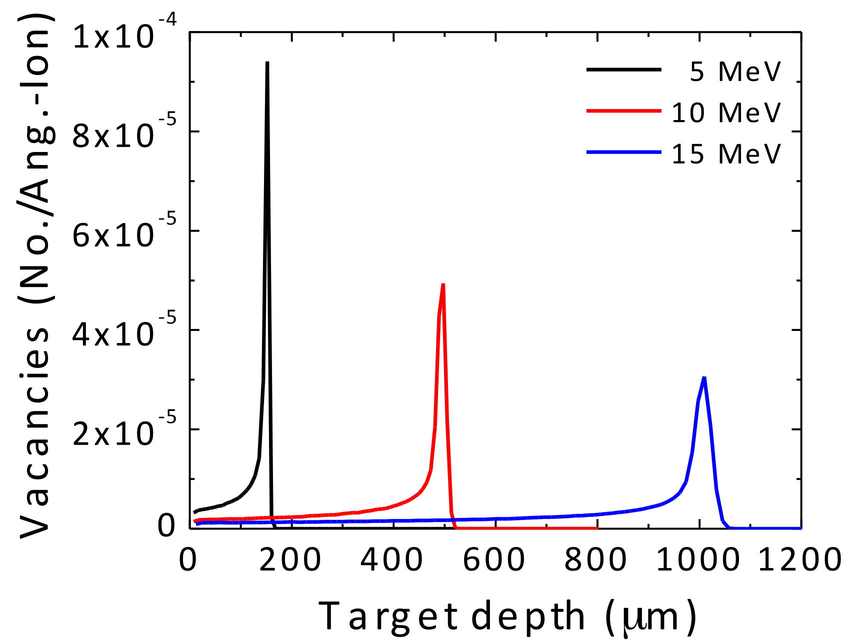
Off-state drain voltage step-stress condition:

Fixed V_G at -6V, stepped drain voltage from +5V to +100V.
Step value = +1V, holding time = 60 sec.

SRIM simulation

(Stopping and Range of Ions in Matter)





Estimated irradiation-induced vacancy densities around 2-DEG channel range from 5×10^{6} to 1.3×10^{11} cm^{-2} for proton-irradiation energies between 5 and 15 MeV.

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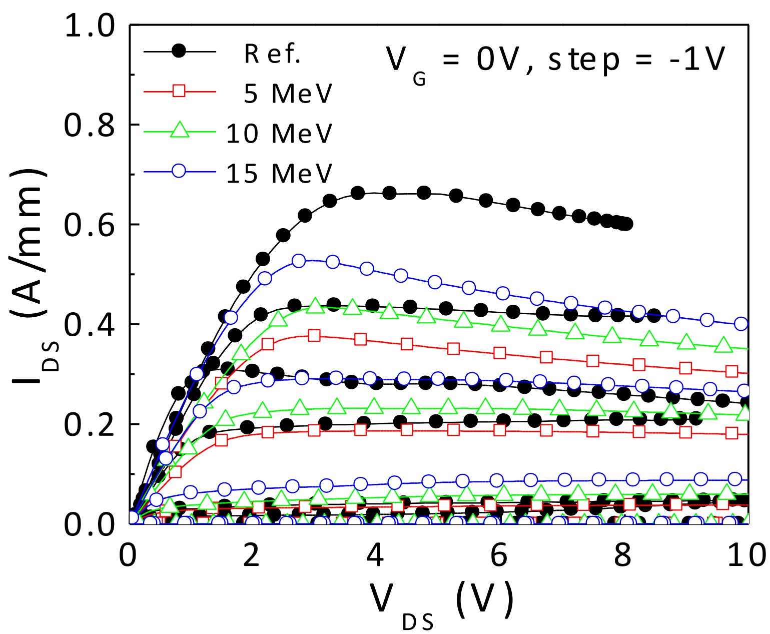
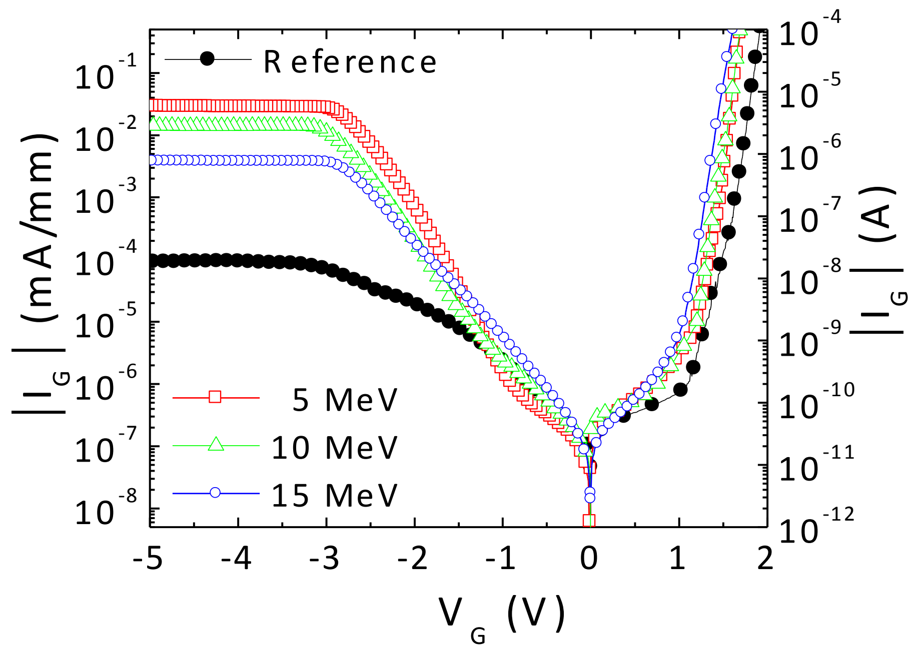
DC performance after proton irradiation

(Fixed dose of 5×10^{15} cm^{-2})





With lower irradiation energy, more reduction of drain saturation current, higher reverse gate leakage current and lower Schottky barrier height were induced.

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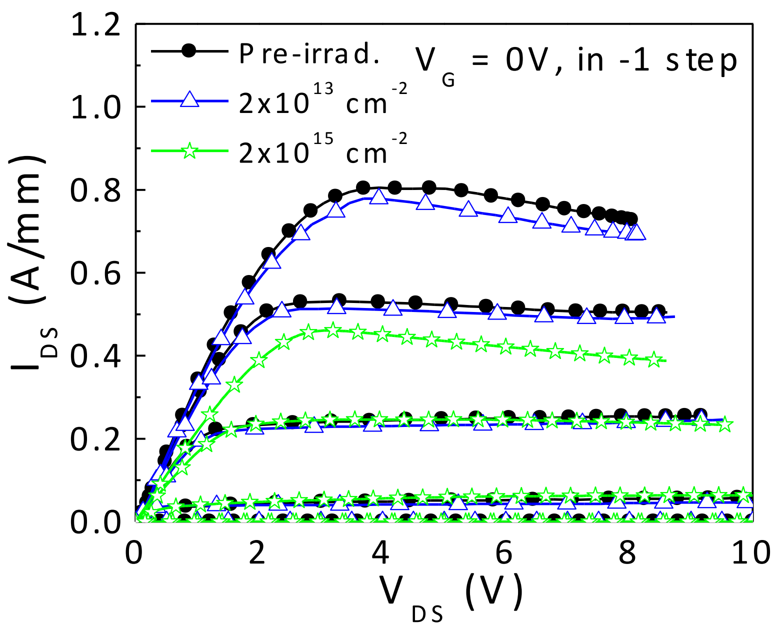
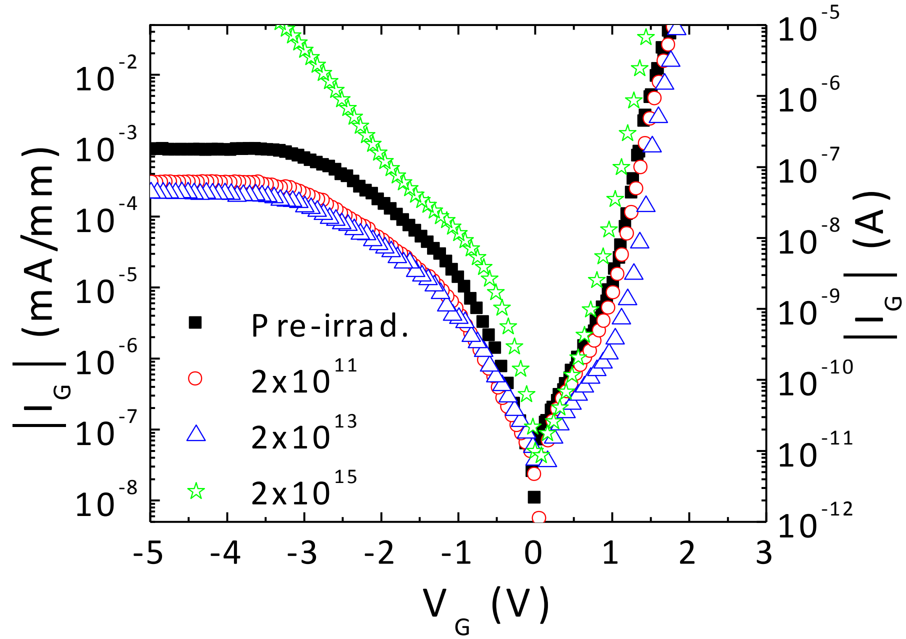
DC performance after proton irradiation

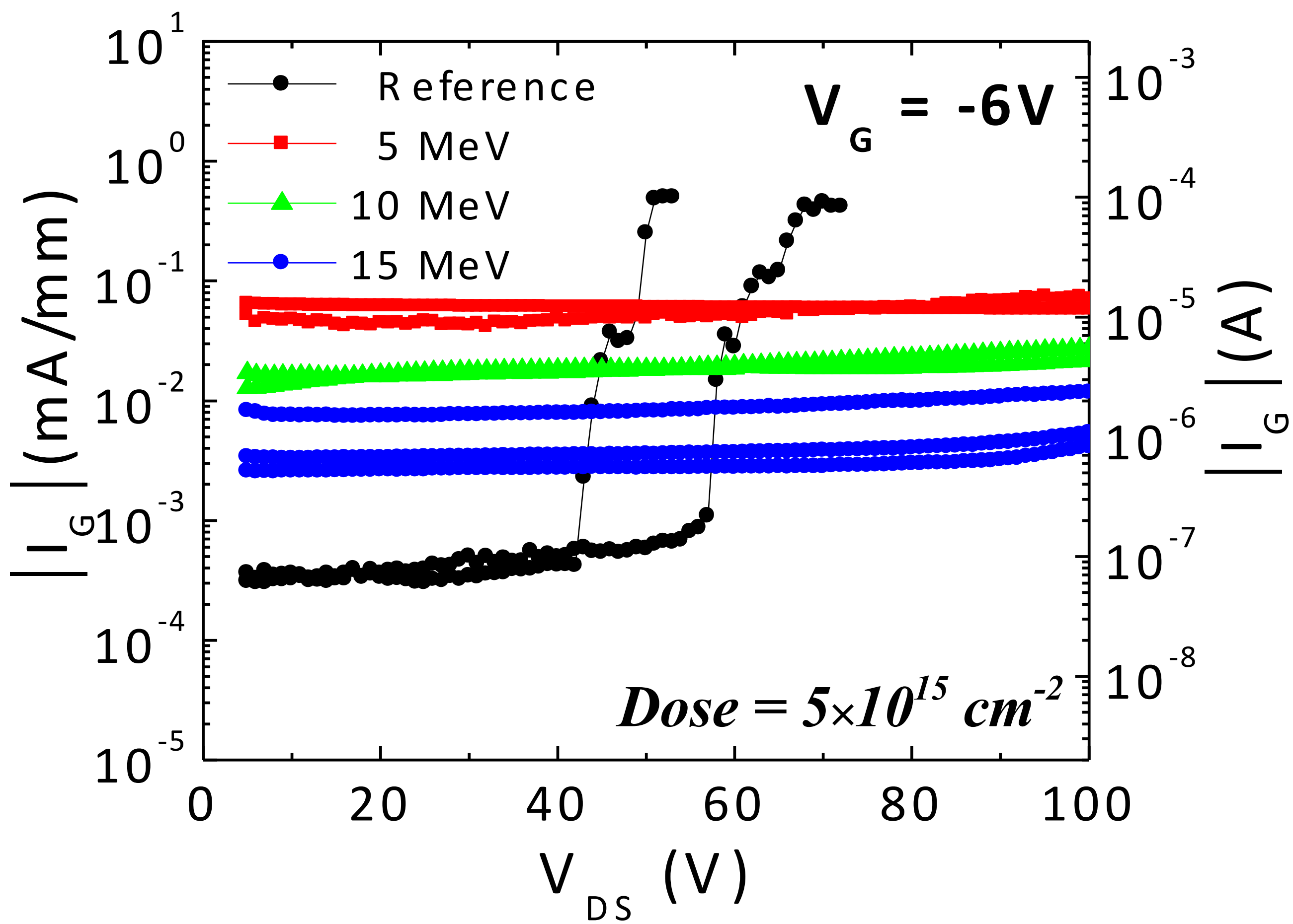
(Fixed energy at 5MeV)





The reduction of drain saturation current increased with irradiation dose.

Electrical stress: (Fixed dose)



As compared to the un-irradiated HEMTs, apparent reliability of proton-irradiated HEMTs was improved.

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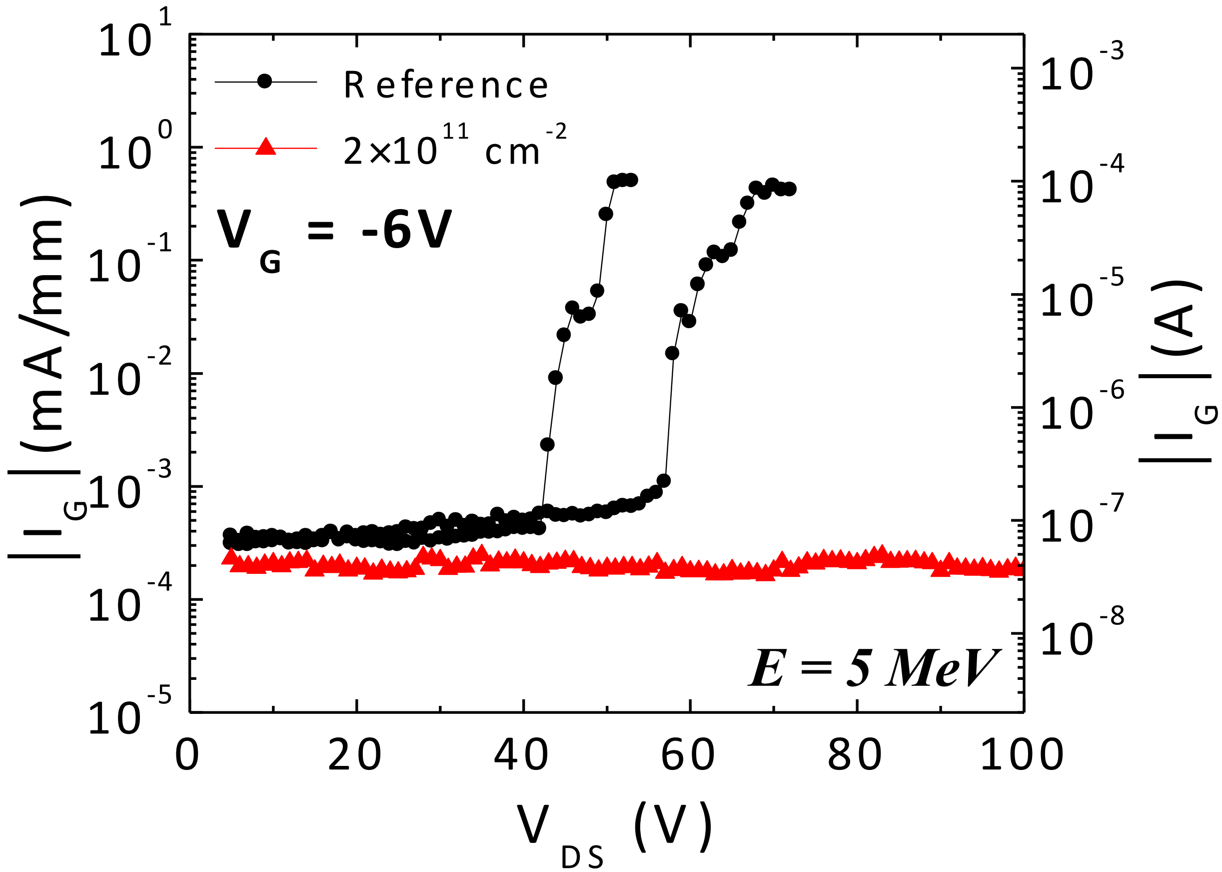
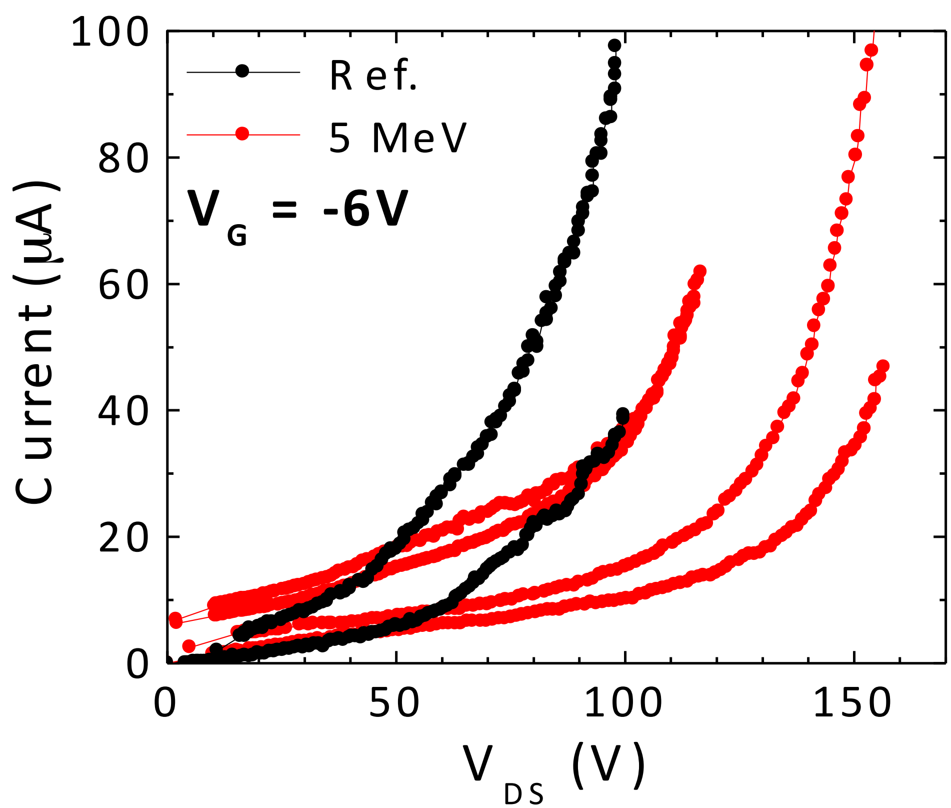
Electrical stress: (Fixed energy)



As compared to the un-irradiated HEMTs, apparent reliability of proton-irradiated HEMTs was improved.

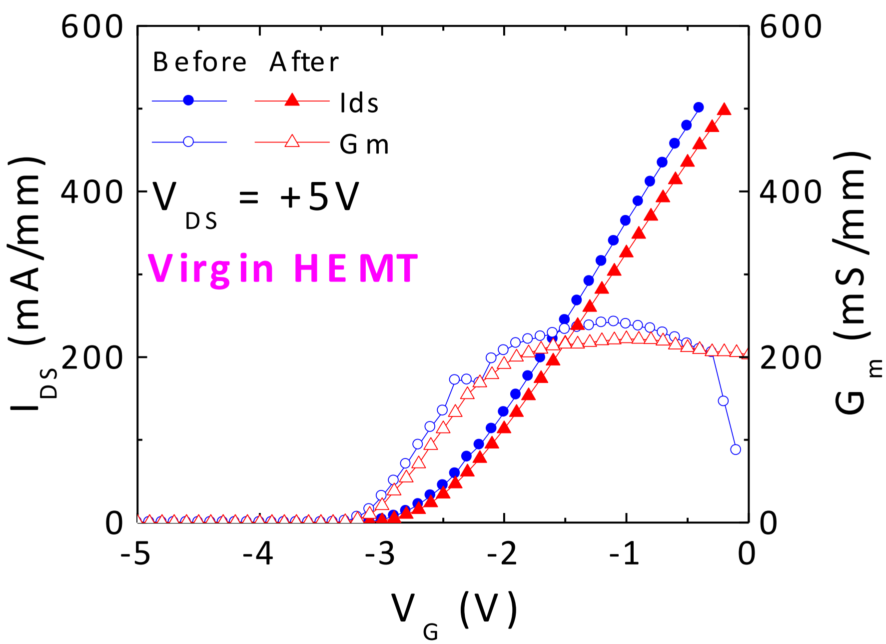
Off-state drain breakdown voltage

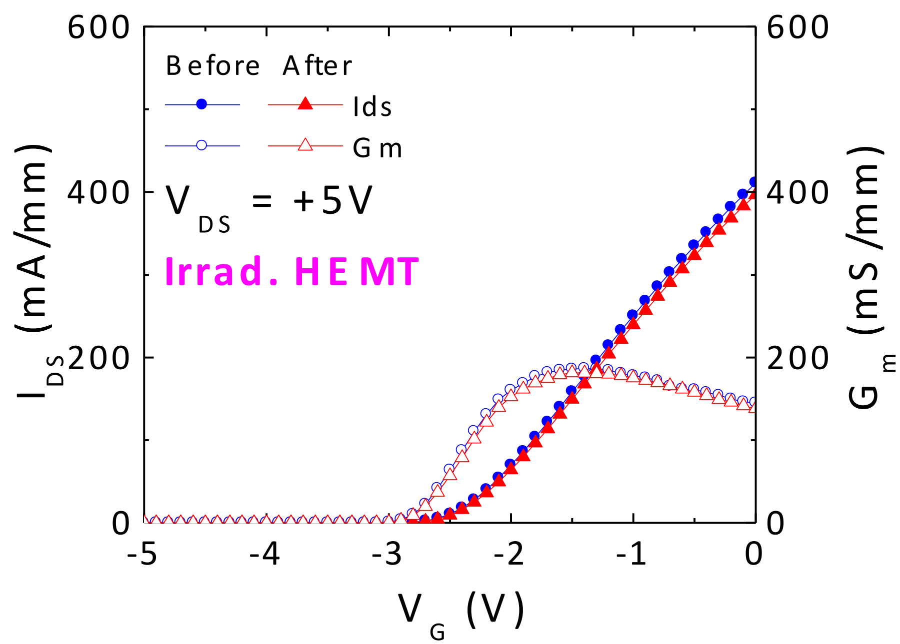


E = 5 MeV
dose = 5×10^{15} cm^{-2}.

The breakdown voltages increased from ~100 V in the reference devices to 160 V in the proton-implantation ones.

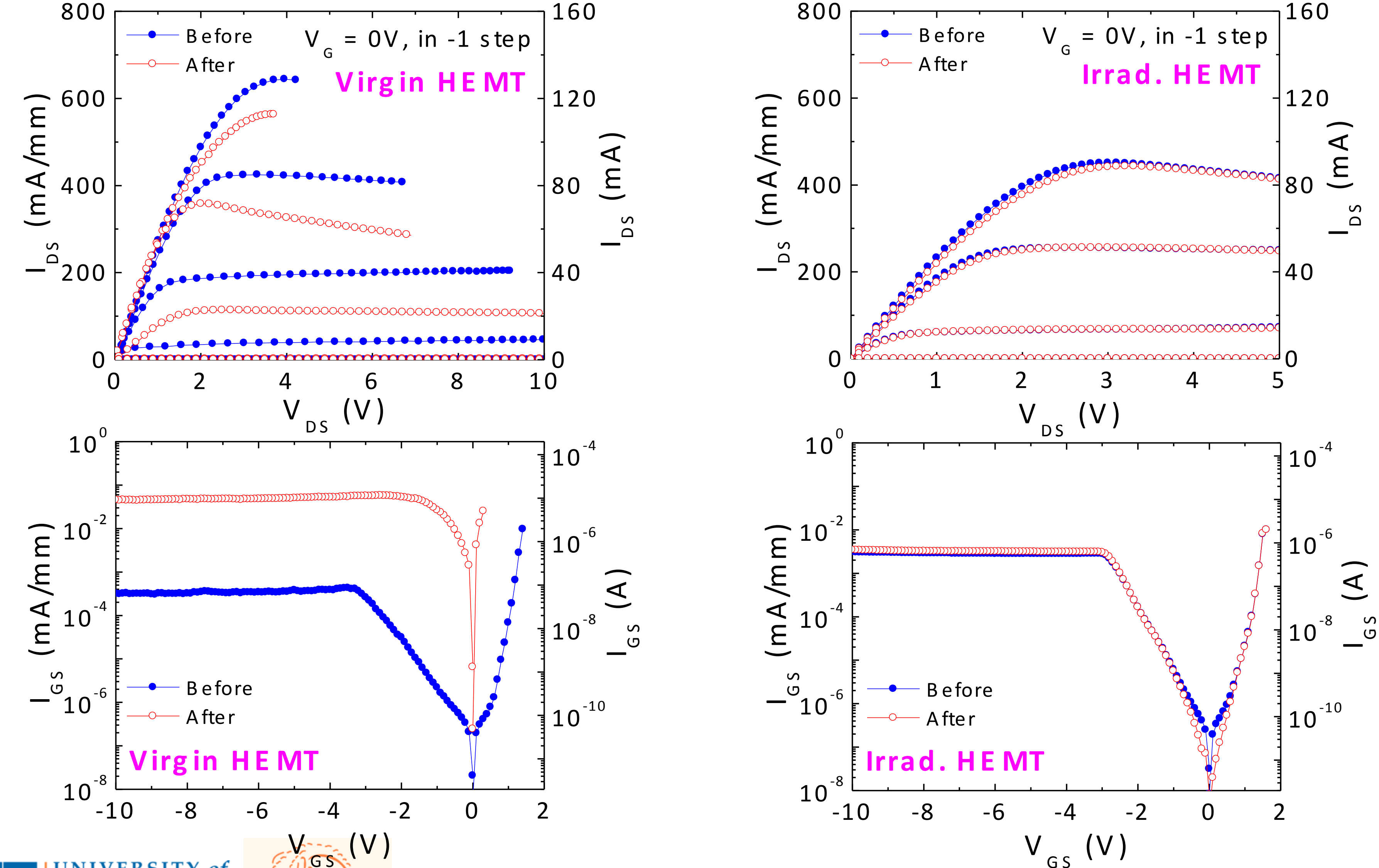
Transfer characteristics:





Minimal change was observed for proton-irradiated HEMTs after electrical stress.

Drain and Gate characteristics:



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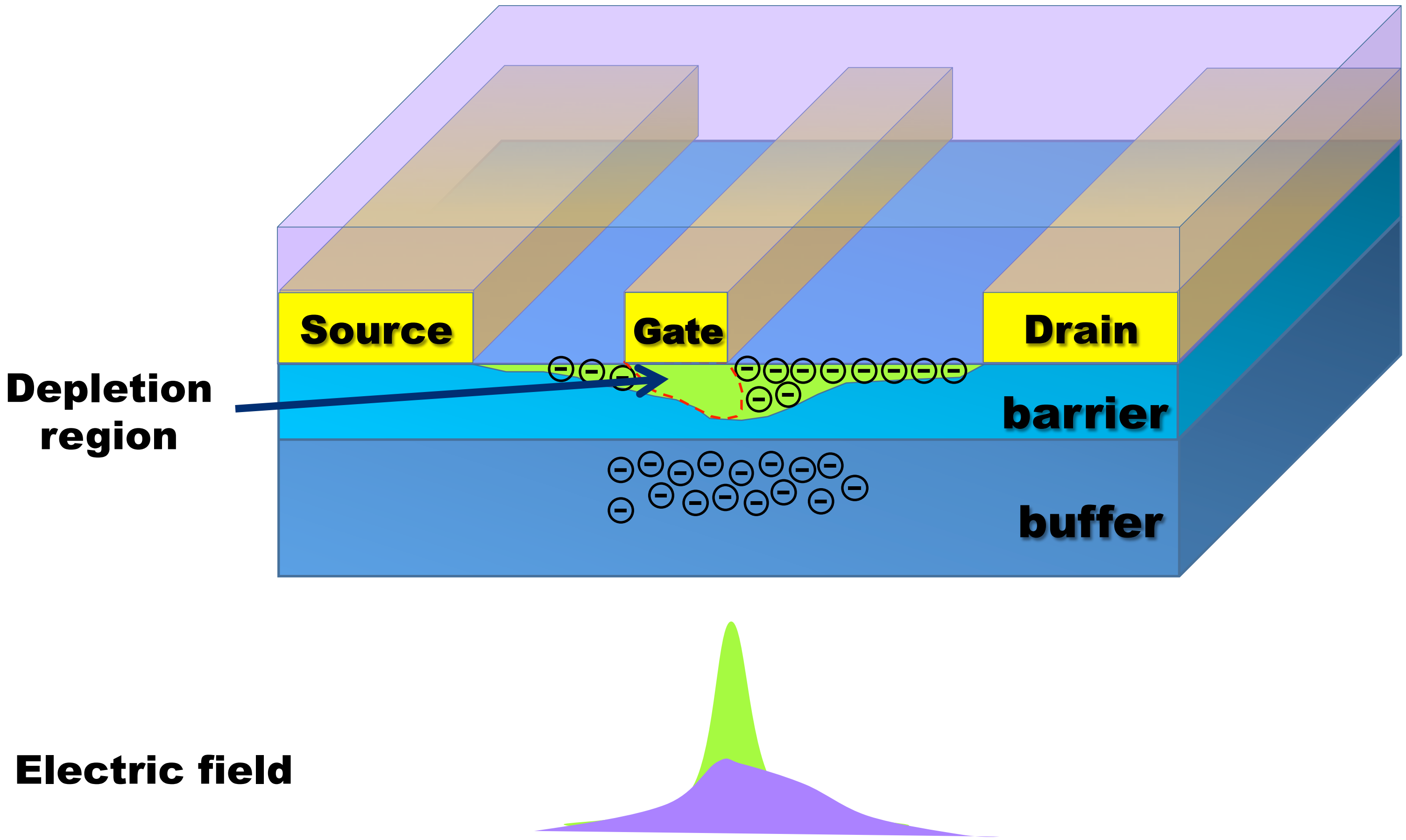
Proposed mechanism:



Part II. Conclusions

- The critical voltage for off-state drain voltage step-stress was increased from ~+50V to above +100 V for proton irradiated HEMTs.

- There were minimal changes in gate and drain current densities, but much higher critical voltage as well as drain breakdown voltage were observed for the HEMTs irradiated with high energy protons at lower doses. Proton irradiation could be used to improve device reliability.

- The large change in critical voltage was tentatively attributed to the virtual gate formation in the damaged buffer layer and lowering of the electrical field around gate.

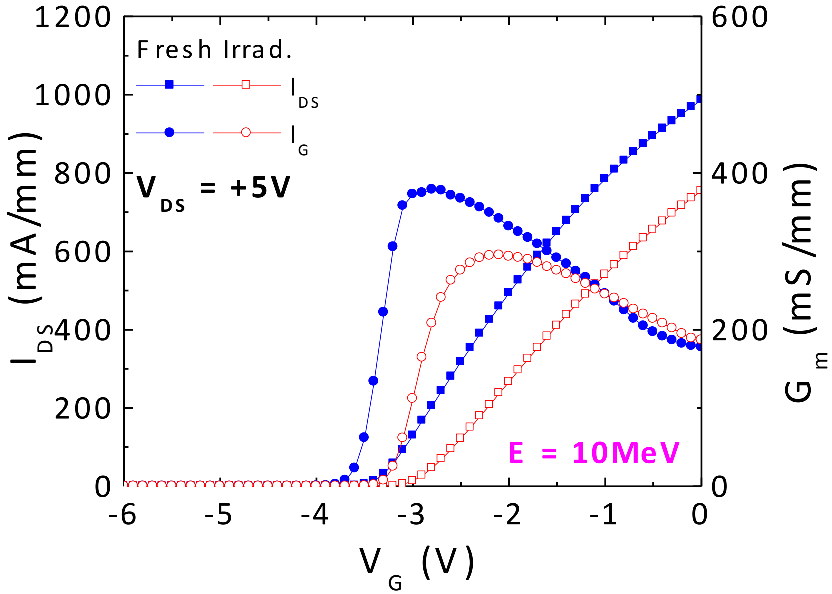
Part III

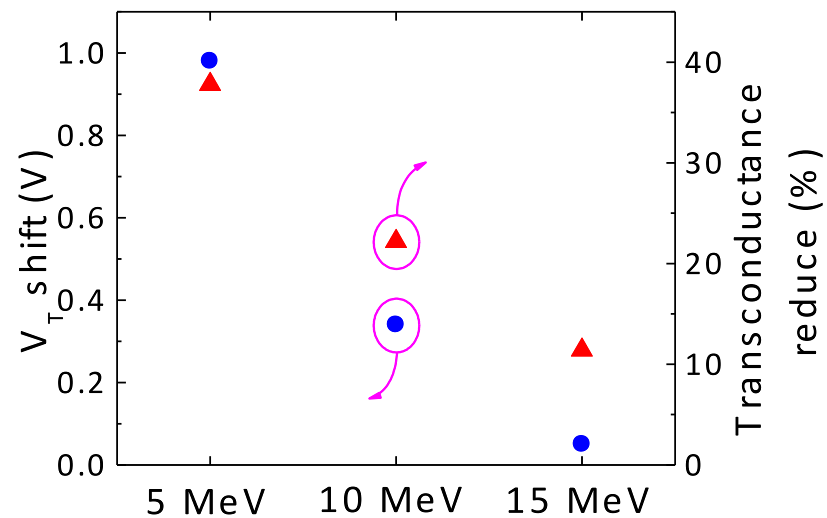
Dependence on proton energy of degradation of AlGaN/GaN high electron mobility transistors

Experiments

Proton energies of 5, 10 and 15 MeV at a fluence of 5×10^{15} cm^{-2}.

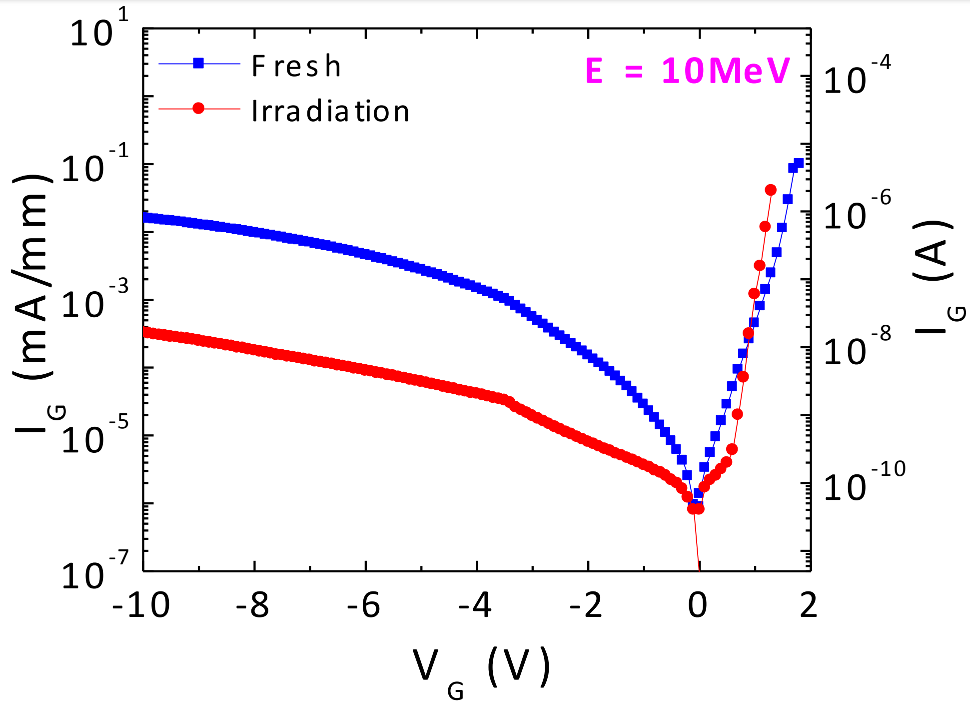
Transfer characteristics:





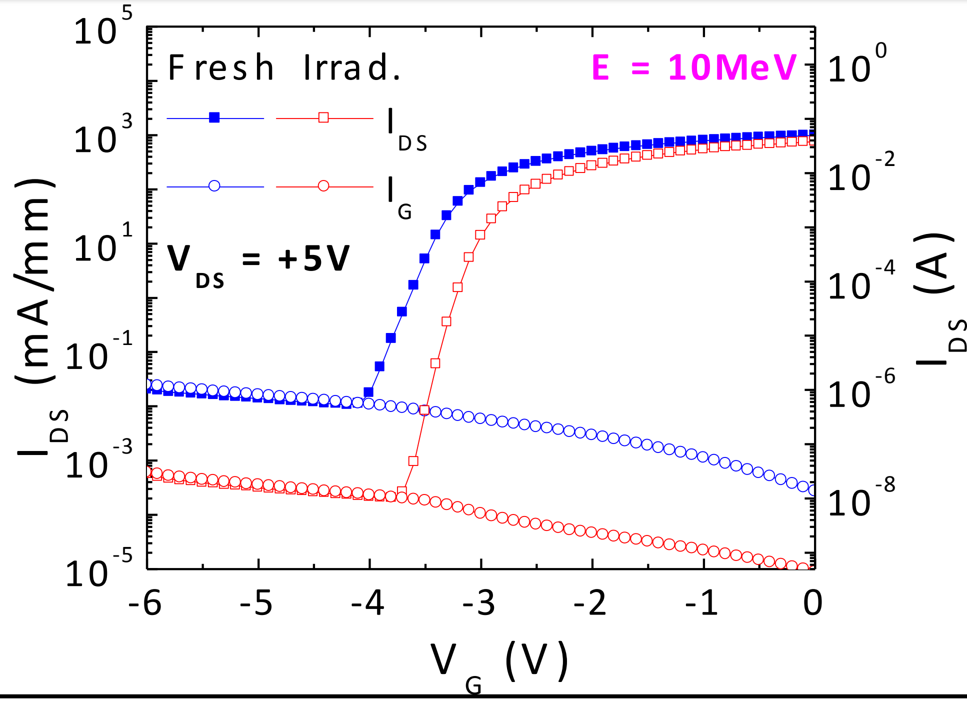
The reductions of maximum transconductance were 11.4, 22.2 and 37.8%, for HEMTs exposed to 15, 10 and 5 MeV protons, respectively.

Gate characteristics:



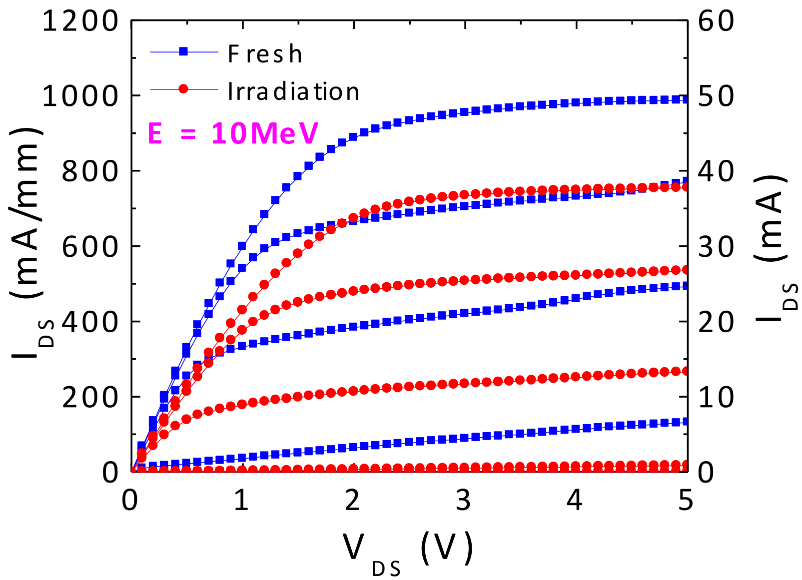
Samples	Condition	I_G at V_G = -10V (mA/mm)	Schottky barrier height (mV)
5 MeV	*Pre-irrad.*	1.3×10^{-2}	730
	Post-irrad.	4.5×10^{-4}	790
10 MeV	*Pre-irrad.*	1.6×10^{-2}	710
	Post-irrad.	3.3×10^{-4}	740
15 MeV	*Pre-irrad.*	1.7×10^{-2}	660
	Post-irrad.	1.7×10^{-3}	690

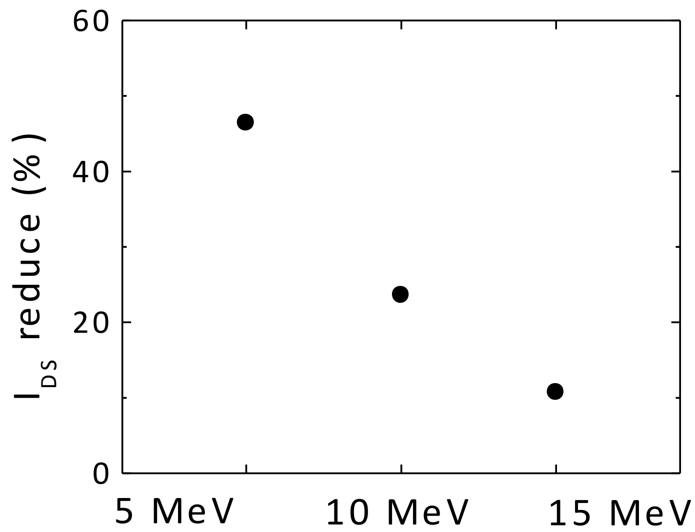
Sub-threshold drain and gate leakage:



Samples	Condition	ON/OFF ratio	Saturation drain current (mA/mm)	Sub-threshold drain leakage current (mA/mm)	Sub-threshold slope (mV/dec)
5 MeV	*Pre-irrad.*	6.3×10^4	999	1.6×10^{-2}	179
	Post-irrad.	1.3×10^6	536	4.2×10^{-4}	159
10 MeV	*Pre-irrad.*	4.9×10^4	986	2.0×10^{-2}	202
	Post-irrad.	1.3×10^6	754	5.6×10^{-4}	124
15 MeV	*Pre-irrad.*	4.2×10^4	980	2.3×10^{-2}	190
	Post-irrad.	9.9×10^5	885	8.9×10^{-4}	172

Drain characteristics:





The decrease in drain saturation current were 9.6, 23.6 and 46.4% for HEMTs exposed to 15, 10 and 5 MeV protons, respectively.

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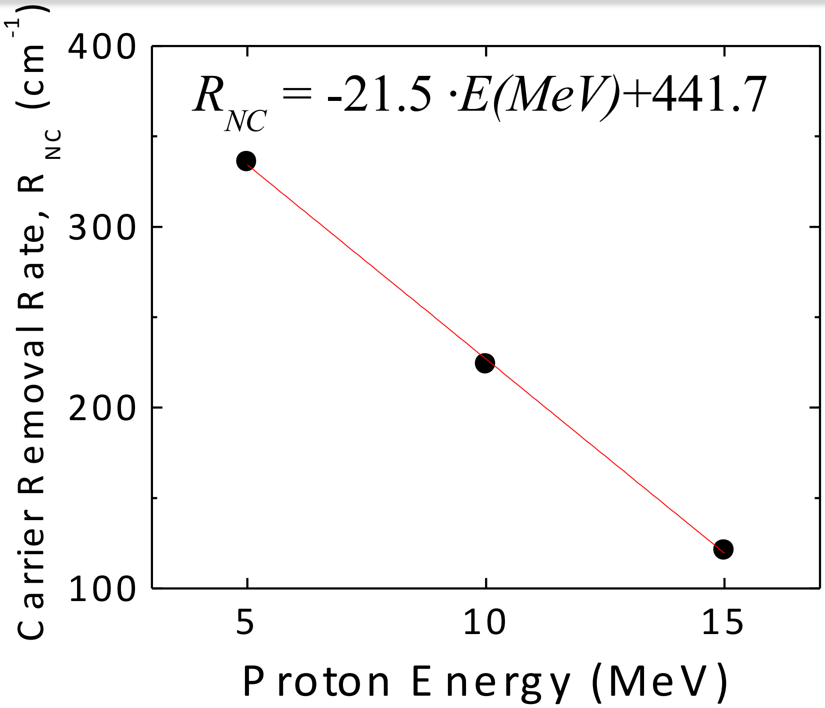
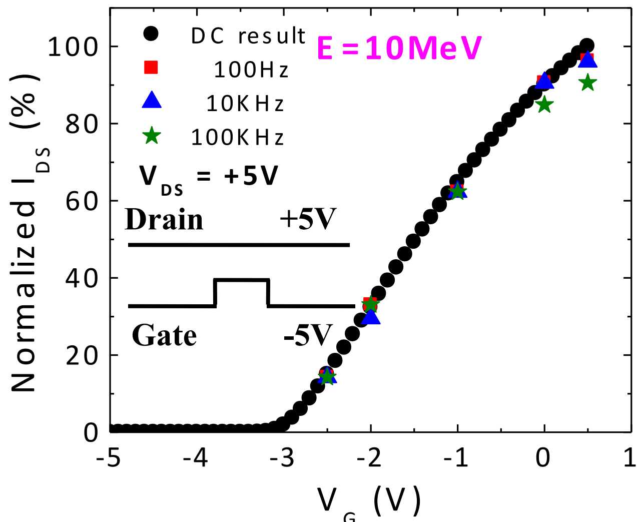
Carrier removal rate:

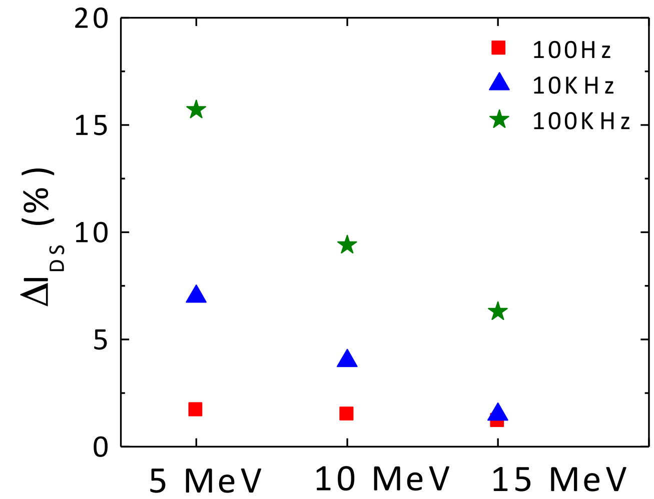


	Pre-irrad.	5 MeV	10 MeV	15 MeV
Normalized mobility	1	0.23	0.38	0.66
Carrier concentration (cm^{-3})	5.8×10^{18}	4.3×10^{18}	4.9×10^{18}	5.1×10^{18}
Sheet carrier concentration (cm^{-2})	7.0×10^{12}	5.2×10^{12}	5.9×10^{12}	6.1×10^{12}
Carrier removal rate (cm^{-1})	–	336	224	121

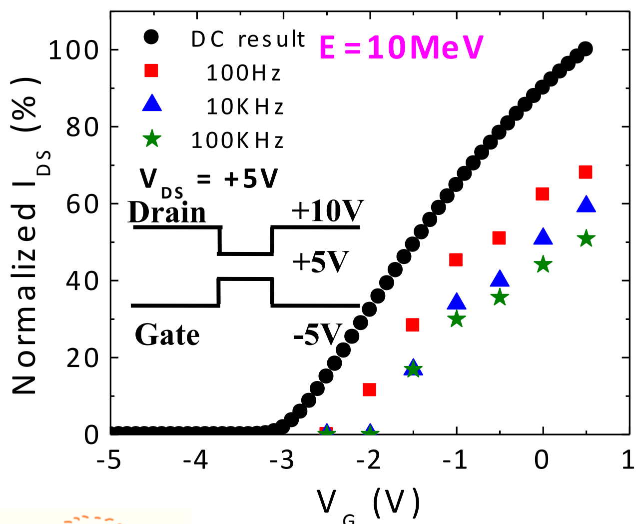
Pulse measurement:

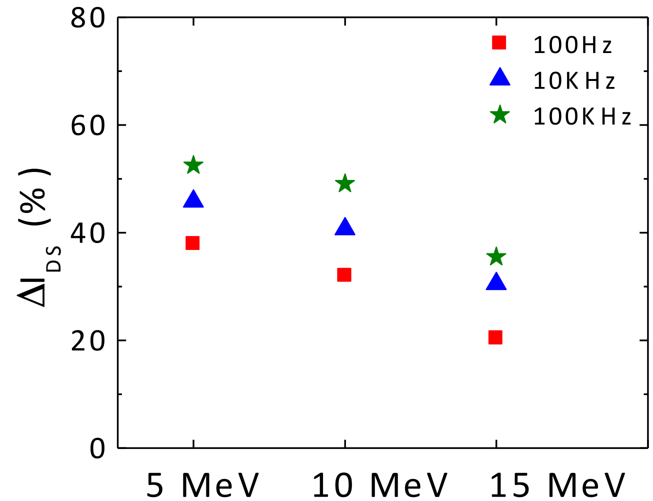
Gate pulse





Double pulse





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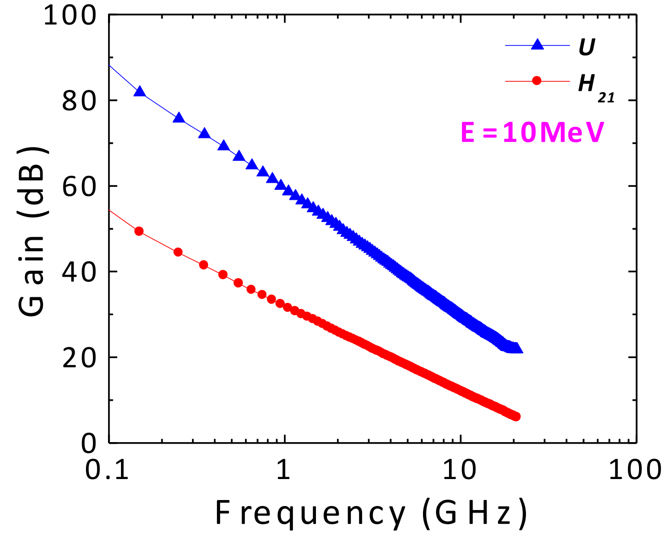
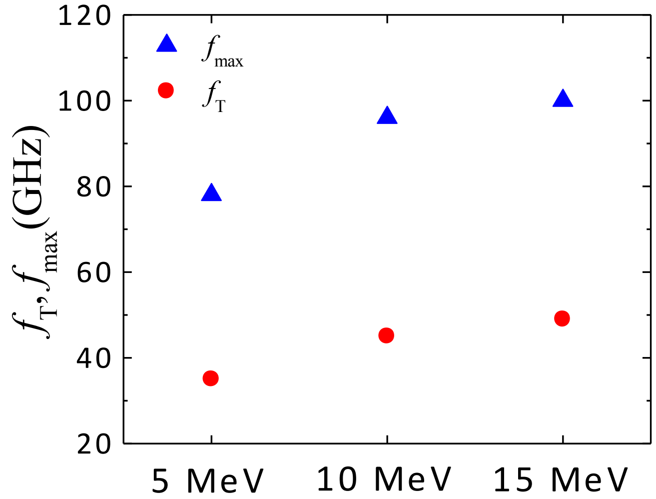
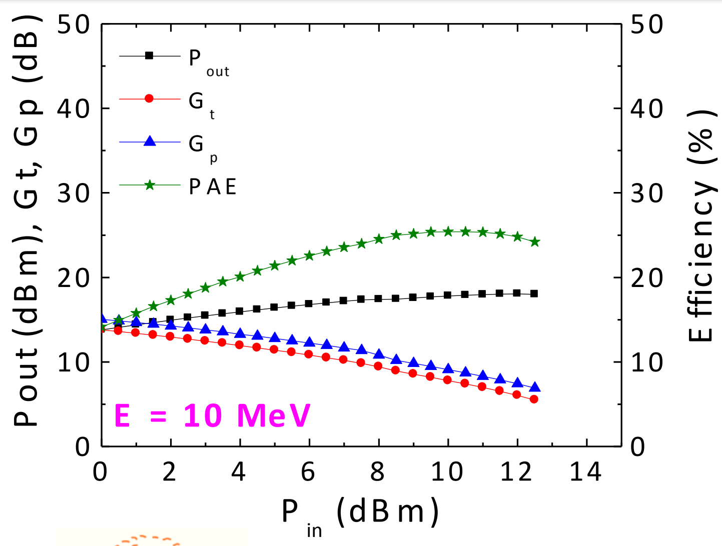
RF measurements:

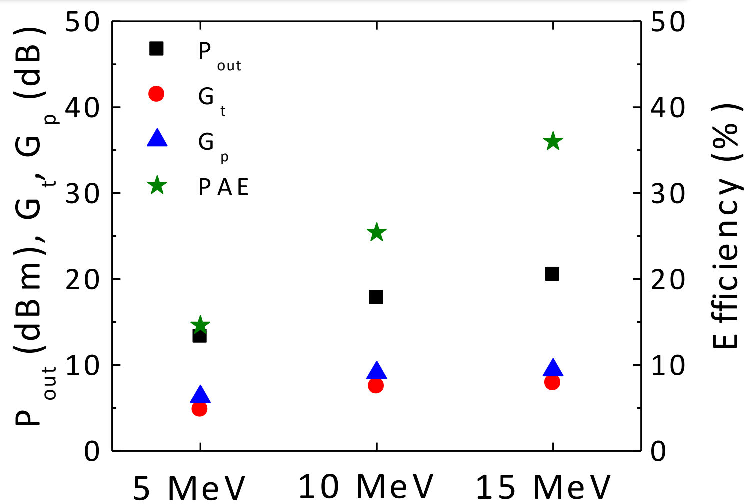
Small signal





Large signal (10GHz)





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Part III. Conclusions

- **Reductions of transconductance peak were 11.4%, 22.2 and 37.4 % and of drain saturation current at V_G = 0V were 9.6%, 23.6% and 46.4% for HEMTs irradiated at 15, 10 and 5 MeV, respectively.**

- **After irradiation, sub-threshold drain leakage current and reverse gate I-V decreased more than one order of magnitude for all cases.**

- **The irradiation-induced displacement damage mechanism, which reduced carrier mobility and charge density, was responsible for more degradation at lower irradiation energy, since more defect centers were introduced close to the 2DEG channel.**